A Novel Atlas of Human Cerebral Cortex based on Extrinsic Connectivity

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1 Introduction

Current theories hold that the human cortex can be subdivided in anatomically and functionally distinct regions, from which interactions cognition arises. In these interactions the long-range axonal connectivity, namely extrinsic connectivity, plays a fundamental role (Passingham et al., 2002). Hence, parceling the cortex taking into account its extrinsic connectivity can help to understand brain's internal organization. However, current brain atlases are based on cytoarchitecture (Brodmann, 1909) or anatomical landmarks (Desikan et al., 2006), which do not necessarily reflect brain's connectivity. Even modern approaches, like that of Glasser et al. (2016) did not include connectivity information on their building process. Using such parcellations on connectivity studies could introduce a bias in the results.

In Gallardo et al. (2016) we presented a logistic random effects model for the cortical extrinsic connectivity and a hierarchical clustering technique based on it. Our technique allows to create a groupwise and multi-scale parcellation of the whole cortex. In this work, we first show the consistency of our technique. Then, we use it to obtain a novel cortical atlas based on the extrinsic connectivity of 138 subjects from the Human Connectome Project (HCP). Experiments show that several of our extrinsic parcels are closely related to brain functionality.

2 Methods

A total of 138 subjects (65 males and 73 females, ages 31-35) were randomly selected from the group S500 of the Human Connectome Project. Each subject was already preprocessed with the HCP minimum pipeline (Glasser et al., 2013) and have a coregistered dense mesh (32k vertices per hemisphere) representing they cortical surface Glasser et al. (2013). For each subject, we performed probabilistic tractography by simulating the movement of 5000 water particles from the vertices of they mesh. Later, we estimated each seed-vertex's connectivity by calculating the fraction of its particles that visited each other seed-vertex.

We randomly divided our HCP subject sample in 3 disjoint groups of 46 subjects each, trying to maintain the same proportion of males and females. Then, we computed each group's groupwise parcellation by clustering their seed's connectivity with our method (Gallardo et al., 2016). To assess our method's consistency, we compared the parcellations at every level of granularity using the adjusted Rand index (Hubert and Arabic, 1985). We generated a baseline for the comparison by computing the similarity between random homogeneous parcellations of the cortex.

After assessing the consistency of our method, we computed a groupwise parcellation from the 138 subjects' connectivity. We encoded it at 55 parcels of granularity as an atlas, since that granularity showed a high average similarity when comparing the 3 disjoint groups.

3 Results

Figure 1.a shows that the similarities between the left-cortex parcellations of 3 disjoint groups (lines red, green and blue) are significantly higher for all granularities when compared with the null case of randomly-generated parcellations (violet). Figure 1.b shows each group's parcellation at 55 parcels of granularity. Figure 2.a shows the atlas computed from the 138 subjects' connectivity for both

hemispheres. Figure 2.b shows a projection of some of our parcels over z-score maps representing average activations to functional tasks from the Unrelated100 HCP population. Figure 2.c shows that the parcels in fig. 2.b contain few negative values and a high proportion of values higher than 5 for a unique task. This shows that our parcels are functionally specialized in accordance with the human homunculus.

4 Conclusions

In this work we showed that our method creates groupwise parcellations consistent across groups. Then, we used it to create an atlas from 138 subjects' connectivity. Our purely extrinsic parcellation showed good agreement with the human homunculus. The obtained parcellation and related tools are available at: http://gagdiez.github.io/EC_atlas.

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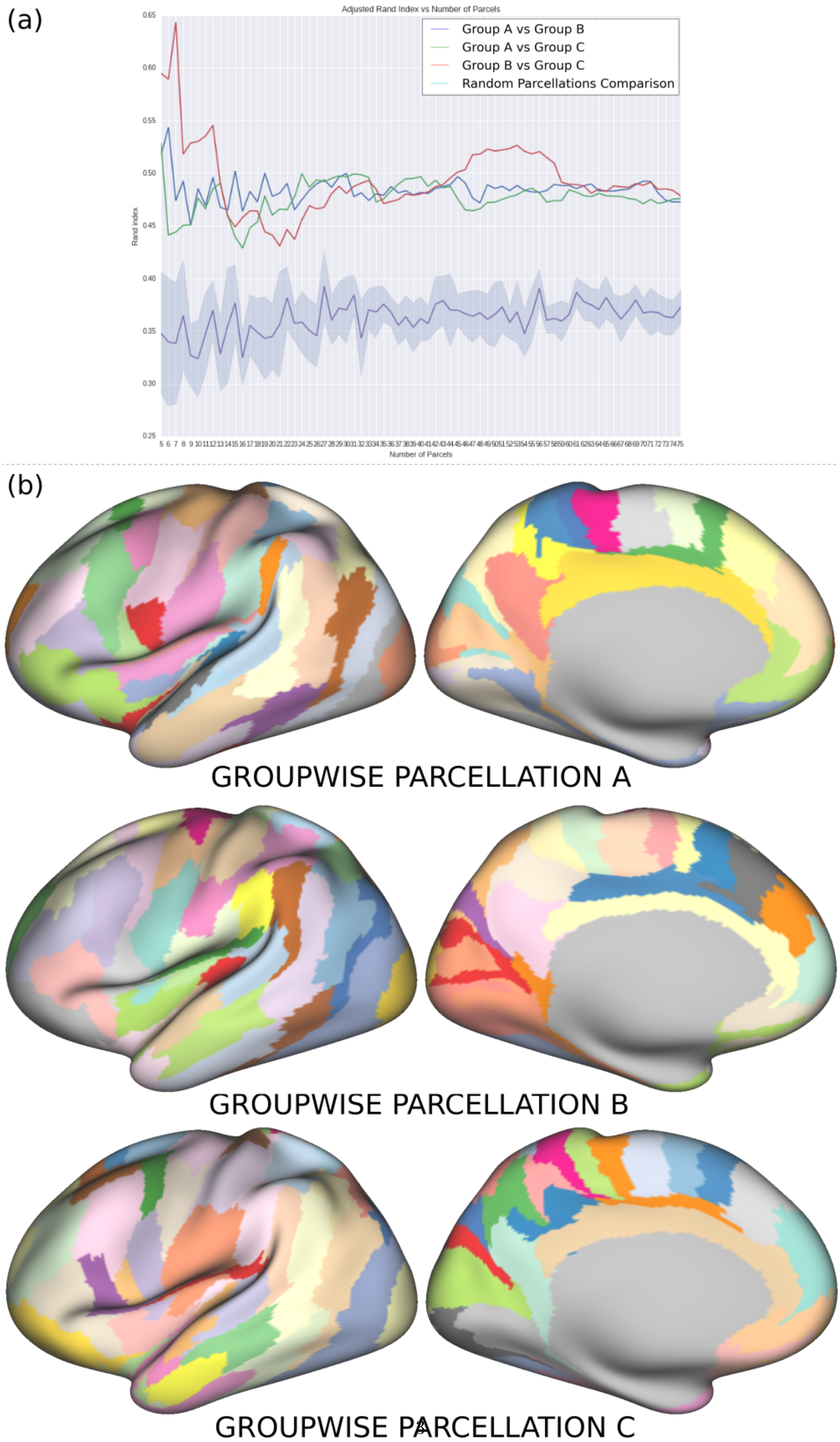

Figure 1: (a) Adjusted Rand Index obtained when comparing: (red) Group A vs Group B; (blue) Group A vs Group C; (green) Group B vs Group C; (purple) Baseline from random homogeneous parcellations. (b) Groupwise parcellations of 3 disjoint groups of 46 people each, each parcellation possess 55 parcels.

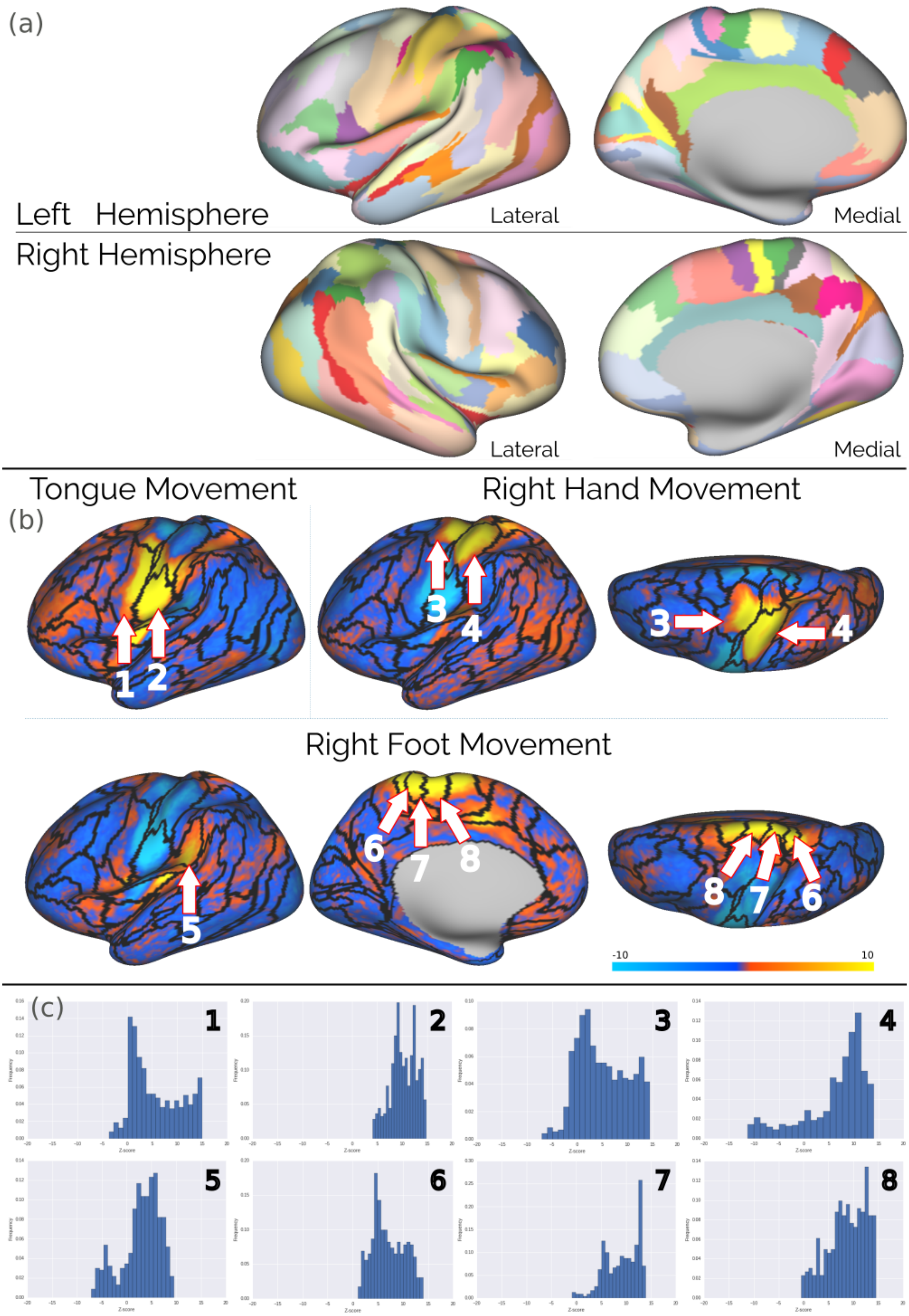

Figure 2: (a) Our extrinsic connectivity based atlas, composed by 55 parcels per hemisphere. (b) Parcels in the motor-sensori cortex projected over z-scores representing activations during hand, foot and tongue movement. (c) Histograms showing the distribution of z-score inside our motor-sensori parcels. The null or small fraction of negative values shows their functional specialization.